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Electromagnetic Spectrum Domination: 21st Century Center of Gravity or Achilles Heel?

A Monograph
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ABSTRACT

ELECTROMAGNETIC SPECTRUM DOMINATION: 21st CENTURY CENTER OF GRAVITY OR ACHILLES HEEL? by MAJ Michael W. Schneider, USA, 60 pages.

The Army is currently embarking on a major peacetime modernization program. As the drawdown comes to a close, the Army is about half its former size and is confronted with a far more complex strategic environment. Virtually any place the Army may be employed, it will be at the end of a long line of communication with its CONUS sustaining base. Furthermore, the Army will have to be wary of simultaneous challenges to United States interests in other theaters. As a result, the Army must be capable of quick decisive victories with minimal casualties in spite of its smaller size.

In order to ensure that the Army is able to meet this standard in its future wars, the Army's leadership has set in motion a modernization plan aimed at maximizing the potential power of a smaller but more lethal army. This modernization plan places a heavy premium on the integrative technologies, (computers and communications), to get more of its forces into the fight at the right time and place and at an ever increasing operational tempo. One by-product of this plan is an increasing dependence on the electromagnetic spectrum to collect and move information on the 21st century battlefield.

This monograph examines the increasing role of the electromagnetic spectrum to determine if the spectrum will become the primary source of strength for the smaller army of the 21st century or a critical vulnerability. It analyzes the Army leadership's vision of 21st century warfare and its modernization plan which is intended to take the Army into the next century. The monograph also investigates the capabilities and limitations of the electromagnetic spectrum to support military operations on the current and future battlefields.

This monograph concludes that the electromagnetic spectrum may in fact become the Achilles Heel for the Army of the 21st century. Knowledge overmatch will be the source of strength which will enable our smaller Army to win quickly and decisively. To ensure knowledge overmatch, the Army will be extremely dependent on the electromagnetic spectrum. The spectrum will also be the enemy's primary means of identifying and disrupting our information systems. Furthermore, physical limitations on the spectrum's capacity to support military operations may ultimately limit the efficiencies which the Army's leadership needs to fight outnumbered and win. To mitigate this vulnerability, the Army must begin testing and training in realistic electromagnetic environments in order to develop effective equipment and doctrine. It also must match its pace of modernization to the rate at which its leaders and soldiers can assimilate the changes.

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I. INTRODUCTION

"Information warfare cannot be waged by a military force unless it can effectively and efficiently control the electromagnetic spectrum."[1] All collection and movement of information relies on some segment of the electromagnetic spectrum whether it be information required by a decision maker, information required by the terminal guidance system of a smart weapon, or the information fed to the enemy as part of a deception or PSYOP plan. The spectrum allows us to leverage information. In the future, battles may be fought in the electromagnetic spectrum to establish spectrum superiority and to set favorable conditions for ground operations similar to the manner in which we currently fight to establish air superiority.[2]

If a nation can develop an operational capability which gives it a qualitative advantage in war, and its commanders can exploit that advantage by effective exercise of the art of command at the operational level, then the possibility for a quick decisive victory exists. Today, the United States possesses a marked advantage in its ability to harness the electromagnetic spectrum for the conduct of war. This advantage is ours by default. No other adversary has the technology in sufficient quantities to challenge the United States. However, history tells us that possession of better technology or equipment does not necessarily translate to a qualitative advantage.

The French tank in 1940 was by all accounts superior to the German tank, the German's qualitative advantage came from their doctrinal concepts for the use of their equipment.[3] These doctrinal concepts were developed during the inter-war period and were derived from an accurate understanding of the effect the tank would have on warfare.

During the Persian Gulf War, the United States had the opportunity to use much of its emerging technology, albeit in early stages of development or fielding. The United States also was able to execute Operation DESERT STORM in accordance with its doctrinal concepts. The outcome, like Germany's victory over France in 1940, was a lopsided victory for the United States and its coalition partners. Iraq was totally outclassed by both our technology and our doctrinal concepts. In both cases, the combination of technology and an effective doctrine gave the winner a qualitative advantage.

Every nation's way of war is influenced by a myriad of factors unique to that nation. The strategic context, past experience, and cultural biases are just some of the factors which contribute to a nation's approach to war. Currently, United States military thinking is heavily influenced by its recent successes in Panama and the Persian Gulf. These operations, combined with a cultural impatience and low tolerance for friendly casualties have led to the requirement for our armed forces to be capable of quick decisive victory with minimum casualties.

Emerging from the Persian Gulf War, the United States has found itself in a strategic environment filled with uncertainties. After years of preparing for war with the Soviet Union, the military is now confronted by a wide range of possible threats none of which can be isolated with any degree of certainty. Simultaneously, we have down-sized the military significantly since Operation DESERT STORM. The combination of these factors forces the military to prepare for a wider range of contingencies with less forces.

We also recognize that our success in Operation DESERT STORM focused the attention of our potential enemies on our technological capabilities and our doctrinal concepts.[4] Failure to continue the evolution of our military technological capabilities and our doctrinal concepts would mean ceding the strategic initiative to our potential enemies and possibly leaving our nation vulnerable to strategic surprise in the next war. Our challenge is not only to change, but to ensure that the changes we make are "about right"[5] for the next war.

Chief of Staff of the Army, General Gordon Sullivan recognizes that today's strategic realities dictate continuous change. In a recent Military Review article, he stated that

> The smaller the Army becomes, the more modern and technologically overmatching it must be. Continuous modernization that exploits leading edge technologies and suggests a clearly defined and well thought out strategy is essential to maintaining our Army's global capabilities.[6]

Military exploitation of the electromagnetic spectrum beyond the visible light portion of the spectrum began with the invention of the wireless radio and progressed steadily until the invention of the computer. Since the invention of the computer, military exploitation of the electromagnetic spectrum has grown almost exponentially. Computers enable data to be digitized so that it can be more easily moved from point to point and so that the data can be more effectively used and manipulated where it's needed. The United States Army's ongoing modernization effort and doctrinal evolution are both aimed at maximizing the possibilities offered by this emerging military technology.

While the military exploitation of the electromagnetic spectrum seems to offer great possibilities for improving the effectiveness of our smaller army, reliance on the spectrum already constitutes a potential vulnerability. Digital data communications are far more fragile than voice.[7] The GPS signal is extremely weak and therefore susceptible to interruption.[8] Black smoke negates the effectiveness of our thermal sights. Many of our more exotic uses of the spectrum such as smart bombs, stealth technology, and Kit 2 filaments were exposed during Operation DESERT STORM.[9] And perhaps the most likely use of a nuclear weapon against us by a regional power is as a high altitude burst for electromagnetic pulse (EMP) effect.[10]

Looking forward in time to the year 2010 and beyond, we will see adversaries who challenge our superiority in key segments of the spectrum.[11] In order for the Army to conduct peacetime change which is "about right" for the next war, it must understand how the nature of warfare is changing and how the Army's changes will interact with the new battlefield. One of the implications of the Army's ongoing changes is the increasing role of the electromagnetic spectrum in 21st century warfare. The most fundamental question which the Army must address is whether the modernization effort is turning the electromagnetic spectrum into a new center of gravity or our Achilles Heel? The degree to which we, as an Army, understand the electromagnetic spectrum's changing role, in terms of technology and doctrine, may dictate whether the spectrum becomes a source of strength or weakness on the21st century battlefield.

In order to gain some understanding of the spectrum's impact on warfare, we must first understand the Army leadership's vision for the future, its modernization plans, the direction of its evolving doctrine, and its methods for implementing change. Understanding the military properties of the electromagnetic spectrum is essential in order to assess whether the spectrum will facilitate change or be a limiting factor. We must either fit the spectrum into our doctrinal model of warfare or redesign the model so that the role of the spectrum is appropriately represented.

II. THE ARMY IN THE 21st CENTURY

> ...it is the task of military science in an age of peace to prevent the doctrines from being too badly wrong. All scientific thought is a sustained attempt to separate out the constants in any situation from the variable, to explain what is of continuing validity and to discard what is ephemeral, to establish certain abiding principles and to reduce them to their briefest, most elegant formulation.[12]

These comments, made by military theorist Michael Howard, summarize the challenge faced by the Army's leadership in today's strategic environment. Michael Howard goes on to say that military science progresses by way of a triangular dialogue within a military bureaucracy between questions of operational requirement, technological feasibility, and financial capability. Of these, Howard said that the development of operational requirements is the most important and the most difficult. "With inadequate thinking about operational requirements, the best technology and the biggest budget in the world will only produce vast quantities of obsolete equipment; bigger and better resources for the wrong war."[13]

What makes thinking about operational requirements difficult is the fact that in peacetime, armed forces must make educated guesses as to the direction that warfare will take as a result of technological and political change. The further a nation gets from its last war, the more it is in danger of missing the mark on its prediction.[14] The penalty for getting it wrong is strategic surprise in the next war.

Occasionally a country will have the opportunity to test its predictions in a "small scale war", what Michael Howard called "way-points" on its path to the future. The United States has had two such opportunities, Operations JUST CAUSE and DESERT STORM. Operation JUST CAUSE demonstrated the power of simultaneous operations throughout the depth of the battlefield. General Sullivan regards JUST CAUSE as the model for future operations.[15] Operation DESERT STORM has been called the first information war.[16] The information differential which resulted from the combination of technology and doctrine gave the coalition forces an indisputable advantage. Michael Howard goes on to point out however, that while these way-points on the course of change may be very useful there will always be doubt because of the uniqueness of every situation.[17]

The Army's Strategic Vision

The United States Army has a strategic vision to take it into the 21st Century. The vision is the product of extensive study of history, military theory, doctrine, and political, technological, economic, and military trends. This vision is expressed through the Army's new warfighting doctrine, FM 100-5, the Army's new capabilities based modernization strategy, and the Army's emerging concept for information operations.

In the September 1993 issue of Military Review, General Sullivan and Colonel James Dubik describe their views on the future of land warfare in terms of the changes in context and technology as well as the continuities. In effect, their analysis describes what Michael Howard called the variables and the constants of warfare. These, variables and constants, "....provide a foundation for examining 21st century warfare."[18] Among the variables, General Sullivan identifies the strategic context within which war is fought as well as technological trends. The constants he identifies are the root causes of war, the role of will, and the essence of fighting power.

The strategic context is changing. The fall of the Soviet Union altered the strategic landscape opening the way for forces of both fragmentation and integration. New challenges, different from the challenges of the Cold War have arisen. At the same time, the nation's economic position has eroded and its social fabric has been torn. The result is that the armed forces will have to do its part to contribute to our economic recovery and social regeneration. "Simply put, international and domestic realities have resulted in the paradox of declining military resources and increasing military missons...It requires fundamental changes in the way the nation conducts its defense affairs."[19] General Sullivan identifies five dominant trends resulting from the military-technical revolution which will have dramatic impact on the Army and the conduct of land warfare in the 21st century: Lethality and Dispersion, Volume and Precision of Fire, Integrative Technology, Mass and Effects, and Invisibility and Detectability.

Lethality on the battlefield is continually increasing. This has driven the requirement for dispersal. The combined effect is the "requirement to communicate over greater distances, to maneuver more quickly and to use fires from platforms of all services that are dispersed over greater distances." This trend implies that it will also become even more important to be able to make decisions more rapidly and to be able to "synchronize the movements of greatly dispersed units..." Finally, greater dispersion will place a greater burden on unit cohesion thus emphasizing the need to build excellent unit cohesion.[20]

The volume and precision of fire on the battlefield will continue to increase for the foreseeable future. Smart and brilliant munitions combined with the integrative technologies which feed the precision munitions with required information will make the battlefield increasingly deadly. The "rise in precision will change the weapons, equipment, organization and tactics of 21st century land forces."[21]

Integrative technologies refers to networked computers that share information across functional boundaries to improve the effectiveness of the organization as a whole. These technologies are rapidly expanding across all segments of society. The military is no different.

General Sullivan calls the introduction of integrative technologies to military operations the "digitization of the battlefield." He theorizes that as a result of digitization, commander's situational awareness will improve by orders of magnitude, that joint task forces will enjoy a common picture of the battlefield thus facilitating the rapid massing of combat power at the appropriate time and place, and that the end result of integrative technology on the battlefield will be an increase in tempo.[22] This increase in tempo will dictate that subordinate leaders continue to be empowered to exercise individual initiative within the commander's intent in spite of the increasing capability to exercise control at higher levels.

As a result of the combination of the first three trends, lethality and dispersion, volume of fire and precision and the use of integrative technology, the fourth trend can be predicted, mass and effects. Mass and effects refers to the trend that smaller units are increasingly able to achieve decisive effects. Through the use of integrative technology and precision weapons the United States can produce fully integrated joint task forces based on smaller units which would be able to achieve the effects which previously would have taken much larger forces.[23]

The final trend concerns the increasing capacity to use electronic means to detect the enemy at greater distances while hiding one's own dispositions. These electronic means, combined with integrative technologies will continue to make the battlefield "more transparent to the commander...and more opaque to his adversary."[24] This logic only holds true if we are able to dominate the electromagnetic spectrum.

The combined effect of these trends in the 21st century will be land forces that

> "will be capable - operating as part of a joint force - of detecting the enemy at extended, over-the -horizon distances while remaining invisible to that enemy; delivering fires-also over the horizon-to facilitate maneuver, thus destroying the enemy force and disintegrating his cohesion throughout the depth of the theater or battlefield."[25]

Forces will possess a deterrent value based on their technological superiority and demonstrated capabilities and as such will be useful to prevent wars but if necessary will be fully capable of decisively winning wars. Their utility will extend through the full range of conflict to include full scale war and operations other than war.[26]

The constants in this time of change revolve around the consistency of human nature. The root cause of war will remain people's "fear, hatred, greed, ambition, revenge, and a host of other quite human and ever-present emotions."[27] In many cases these emotions will be evoked or inflamed unwittingly as a result of strategies which fail to account for cultural differences. Another constant is the fact that war will remain a contest of wills between its participants. It is interactive in nature and will always require the utmost in skill, creativity, and intuition in spite of the advantages afforded by the harnessing of the technological trends. Finally, the essence of fighting power cannot be obscured by the "glitter" of technology. Martin Van Creveld describes the essence of fighting power as "discipline and cohesion, morale and initiative, courage and toughness, the willingness to fight and the readiness, if necessary, to die."[28]

Having reached conclusions as to the direction of change in terms of variables and constants, the Army's leadership has outlined a capabilities based modernization strategy to take the Army into the 21st century. Michael Howard would refer to these capabilities as operational requirements. The Army's capabilities based approach to modernization marks a change from past practices. It is not simply the possession of superior equipment that counts in war, but rather the combination of that equipment with a sound doctrine for its use. By choosing to follow a capabilities based modernization strategy, the Army is linking the development of horizontally integrated warfighting technology with the development of doctrine in order to produce a set of capabilities which are intended to keep the Army ahead of the forces of change which eventually will sweep everyone into the 21st century. The trick is to assure that the underlying assumptions are correct or if they are disproved, to make the necessary adjustments to the strategy. The capabilities which the Army will pursue are:

Project and Sustain: Since the Army has transitioned from a forward deployed force to a CONUS based force, it must rethink how it will get to the fight and stay in the Fight.

The "Army must have the ability to project itself to any region of the world and sustain itself at a high tempo."[29] The modernization strategy envisions using integrative technology, i.e., computers and data communications, to lighten the load, decrease the amount of support, and gain "total asset visibility" to make sustainment more efficient and to down-size units. At the same time we need to upgrade the deployment infrastructure of our CONUS bases.[30] Projection and sustainment overmatch allows U.S. forces to fight beyond the enemy's culminating point.

Protect the Force and Preserve Freedom of Action. Protection from high technology threats becomes increasingly important as our forces shrink and the threat grows. Integrative technology offers great opportunities in the areas of theater missile defense, counterfire, and combat identification. The upgrade of individual protective equipment will also be a priority.[31] All military operations involve the dilemma which concerns how to defeat the enemy before he can do the same to you. Protection from the enemy broadens the options available to defeat the enemy by conserving forces and by taking away the enemy's ability to interrupt your plans. A force protection overmatch allows the commander to focus on the enemy.

Win the Battlefield Information War. The qualitative advantage the Army would have if it can assure that its forces can "Collect, process, and use information about the enemy, while denying the enemy the same intelligence of friendly forces, is invaluable and incalculable."[32] By winning the information war we would be able to "sustain a crushing tempo". In order to achieve this capability, we must be able to "see, hear, disrupt, deny, communicate and out think the enemy"[33] Winning the information war means information overmatch. Information overmatch enables synchronization to devastate the enemy, it permits a shared awareness of the tactical situation throughout the combined arms team, it facilitates automated C2 on the move for faster decision making, reduction of fratricide, and reduction of sensor-to shooter time. The commander with the clearer operational view of the battlefield is able to mass forces more effectively. [34]

Conduct Precision Strikes: The desired effect of precision strikes is to deny enemy maneuver. Precision strikes allow U.S. forces to "reach deep to strike enemy logistic, combat and command formations, and lines of communications". In order to achieve the desired effect of precision strikes, we must have highly reliable information and smart/brilliant munitions employed simultaneously throughout the depth of the battlefield. Once again, integrative technologies will be fundamental to our ability to realize the capability. Effective precision strikes allow the commander to shape the battlefield.[35]

Dominate the Maneuver Battle: The cumulative effect desired from the combination of the first four capabilities is to allow U.S. forces to dominate maneuver. By conducting simultaneous precision strikes throughout the depth of the enemy to "destroy, disrupt and control the threat information flow" while protecting our own forces and C2 and then acting on our information differential, we can dominate the maneuver battle. Digitization is the answer to the question of how the Army can maintain its combat dominance on the future battlefield in spite of a smaller force structure. "The focus of information dominance is technology."[36] Information overmatch allows the commander to "concentrate the lethality of his assets without concentrating and expending his forces."[37] The combination of all five capabilities enables the commander to establish a high tempo while controlling the enemy's tempo. The effect is unchallenged initiative leading to quick, decisive victory with minimum casualties.

Integrative technology is a common theme which runs throughout discussion of each of the five capability requirements for the 21st century. These five capabilities are in fact the ulterior motives behind our increasing use of the electromagnetic spectrum. Integrative technology is fundamental to our ability to achieve more combat power with smaller and less forces. As such, the Army has developed the Army Enterprise Strategy to unify all the various integrative technology initiatives toward the common purpose of "supporting U.S. Army warfighters into the 21st century."[38] It outlines the "strategy and principles by which we will exploit current and future information technologies..."to achieve the five capabilities discussed above. The principles of the strategy are: Focus on the Warfighter, Enforce Joint

Interoperability, Capitalize on Space-based Assets, Digitize the Battlefield, Modernize Power Projection Platforms, Optimize the Information Technology Environment, Implement Multilevel Security, Ensure Spectrum Supremacy, Acquire Integrated Systems Using Commercial Technology, and Exploit Modeling and Simulation.[39]

Among these principles, one stands out, Ensuring Spectrum Supremacy. Each of the other principles involves guidance on the acquisition and development of C4I technology whereas Ensuring Spectrum Supremacy cautions that the U.S. Army is in a position of "extreme dependence on the spectrum".[40] As such, the principle mandates that a technological and a doctrinal solution is required. It also calls for the development of "weapons to deny the enemy exactly the capability we wish to reserve for ourselves."[41]

Having identified the Army leadership's vision for the operational capabilities that will be needed in the 21st century, we should recall Michael Howard's comment that military science progresses by way of a triangular dialogue within a military bureaucracy between questions of "operational requirement, technological feasibility, and financial capability".[42] Throughout the vision we have seen the influence of financial capability. The trend is clear, military budgets are decreasing and it does not appear they will increase in the foreseeable future. At the same time the processing power of computers has undergone a "steady sixty fold increase of power per dollar over eleven years" or a "doubling time of only eighteen months. Communications throughput rates, magnetic and optical storage capacity, and sensor sensitivity show similar progress".[43] The operational requirements identified by the Army leadership reflect sound theoretical thought on the capabilities which will be necessary for a smaller force to win on the battlefield of the 21st century. The parallel issues of technological feasibility and financial capability are less clear.

The truly strategic question is how much leverage will the smaller Army get out of its technological and doctrinal changes? This modernization strategy constitutes somewhat of a risk, as any plan does. The integrative technology upon which we are counting is not entirely proved. The complexity, the acceleration of time, the need to have humans in the loop at all levels, and the role of emotion on the battlefield are examples of differences between the use of automation in the civil sector and in the military. Additionally, while communications throughput rates have made great advances overall, at the tactical level the information rate is the same as it was 11 years ago, 1200 bits per second,[44] extremely slow by modern standards. Another, and perhaps the most significant difference between civil use of integrative technology and military use is that in the military, the enemy is actively trying to interrupt or destroy your ability to function. No one should expect the digitization of the battlefield to result in perfect intelligence, perfect situational awareness, or total asset visibility. On the other hand, we should expect value added. But how should we measure the value added? Determination of this answer is necessary to judge whether the impact of integrative technology will be sufficient to give the smaller Army a qualitative advantage in the next war. The answer to this question is same as the answer to the question of whether the United States will be the victim of strategic surprise in our next war. No one can know for sure. Perhaps all we can really know is that if we could go back to DESERT STORM, we could win more quickly with even fewer casualties.

Implementing the vision will have a major impact on how much value added can be derived from modernization. Technology insertion is only part of the plan, the other part is doctrine. In June 1993, the Army published the newest version of its keystone warfighting doctrine, Field Manual 100-5, Operations. From a warfighting perspective it goes beyond air-land battle to full dimensional operations. It also broadens doctrinal thought to include operations other than war. FM 100-5 marks the evolution which is taking place in warfare by introducing several new concepts while keeping many of the old principles which have survived the test of time. Among the new concepts are battle command, battle space, and depth and simultaneous attack. [45]

Battle command is defined as "the art of battle decision making, leading, and motivating soldiers and their organizations into action to accomplish missions".[46] Battle command raises the commander above the technology driven command systems and establishes the purpose for those systems, to support the commander's decision making and leadership functions on the battlefield. Battle command emphasizes the artistic aspect of command. It drives the requirements for many of the technical aspects of the C2 systems which are currently on the drawing boards. Battle command gives focus to integrative technology in both design and practice. Battle command effectiveness is ultimately the effect integrative technology is supposed to facilitate.

Battle space is that space which is determined by the maximum capabilities of a unit to acquire and dominate the enemy. It is a physical volume that expands or contracts in relation to the ability to acquire and engage the enemy. It also includes the dimensions of time, tempo, depth, and synchronization. The concept of battle space is used to help the commander to determine how the terrain and his forces can be used to dominate the enemy. The commander should strive to minimize the enemy's battle space while maximizing his own. The commander should consider all friendly assets which can be brought to bear on the enemy, not just his own. This implies a joint orientation.[47]

A theme which runs throughout FM 100-5 is the concept of depth and simultaneous attack. This concept goes beyond precision strike. It includes maneuver forces as well. The concept is viewed as vital to our ability to win quickly with minimum casualties. The effect of depth and simultaneous attack works as much in the psychological realm as in the physical.[48] Simultaneous attack throughout the depth of the battle space is how we intend to accelerate tempo and paralyze the enemy. It is the ultimate in high tempo operations and it requires the most in terms of synchronization and the benefits of the integrative technologies. Depth and simultaneous attack implies joint non-linear operations which blur the distinctions between the strategic, operational, and tactical levels of war.[49]

Since the publication of FM 100-5, the Army has done a great deal of work in developing a concept for information operations. On 8 March 1993, the Chairman of the Joint Chiefs of Staff issued Memorandum of Policy number 30 (MOP 30), entitled "Command and Control Warfare". This document represents the realization by the U.S. military that all combat power ultimately flows from the commander's ability to envision the battlefield, make appropriate decisions, and motivate and lead his forces in the accomplishment of their assigned missions. This is conversely true of the enemy's forces. MOP 30 establishes C2 warfare as a strategy that "is required in all aspects of military operations as an integral part of the overall theater campaign plan."[50] C2 warfare combines OPSEC, PSYOP, military deception, electronic warfare, and physical destruction to deny information, influence, degrade, or destroy the enemy's C2 system while simultaneously protecting our own. MOP 30 states that C2 warfare is a joint strategy that will "contribute to the security of friendly forces, bring the adversary to battle on our terms, seize and maintain the initiative, ensure agility, contribute to surprise, decapitate enemy forces from their leadership and create opportunities for a systematic exploitation of enemy vulnerabilities."[51]

The Army's response to MOP 30 has been the proactive development of comprehensive doctrine to incorporate the intent of MOP 30 into the Army's way of fighting. The Army published a coordinating draft of its Information Operations Concept on 7 February 1994. Information Operations is an umbrella concept which "describes the framework for the Army to conduct information warfare employing integrated Command and Control (C2) and Command and Control Warfare (C2W), supported by intelligence as an integral part of joint, combined, or interagency operations."[52] It states that Information operations are "a new form of warfare equally as important as ground, air, and sea operations" in an environment where information/knowledge has become a "critical center of gravity".[53]

At the strategic level, information operations uses information security, OPSEC, deception, and PSYOP as deterrence measures to achieve our objectives without war. If deterrence fails, EW and physical destruction are also used to disrupt enemy C2. At the operational level, the "objective is to restrict the size of the adversary's battle space while creating the largest battle space possible for his own forces."[54] Operational commanders use OPSEC, PSYOP, deception, EW, and physical destruction to paralyze the enemy through counter-C2 actions while simultaneously using C2-protect actions to safeguard his own information systems. At the tactical level, commanders use "simultaneous operations designed to disrupt or destroy enemy C2 systems allowing them to defeat enemy forces in detail."[55] The objective is to use information operations to "enhance their combat power and increase their tempo relative to that of enemy forces."[56]

Information operations use all five of the required capabilities called for by General Sullivan in the Army's modernization strategy. Information operations not only use integrative technologies, it depends on them. Information operations also requires "assured global, mobile, secure interoperable (joint and combined) communications carrying voice, data, imagery, and video."[57] "A principle objective of Information Operations is to create an inequality between the efficiency of the friendly commander's decision making cycle and the adversaries (sic)."[58] This is the qualitative advantage the Army is striving for with the combination of its technological and doctrinal changes. From an operational art perspective, winning the information war is what each level commander must do to set favorable terms of battle for his subordinate commanders. It allows him to set the tempo and dominate maneuver. It gives the commander more options than his enemy (freedom of action) and leads to the ability to seize and retain the initiative.

Information operations provides an intellectual foundation for the application of modern technology on the battlefield. For the most part we are referring to technological innovations which either assist us in the sorting, managing, and processing of data or which exploit the electromagnetic spectrum for military purposes. Digitization of the battlefield involves the horizontal integration of technology to automate as many battlefield functions as possible, to share data throughout the battlefield via digital data communications across a global communications grid, to fully exploit the electromagnetic spectrum for intelligence and counter-C2 purposes, and to maximize the effectiveness of weapons through smart and brilliant munitions.

Digitization requires "intra-army and joint and combined interoperability and the provision for tailorable functionality to provide access to the 'relevant' common picture at all echelons...".[59] There are a whole host of technical and functional issues which will challenge our ability to quickly digitize the Army. Many of our existing systems, which were developed prior to the concept of digitization will be difficult to "reverse engineer" to achieve interoperability or to be able to handle the data load. These problems will be overcome with time and money and a systematic approach to the integration of this technology with the doctrine of Information Operations and FM 100-5 to achieve the Army's five modernization capabilities.

The Army's systematic approach intends to use the Combat Training Centers, simulations, Louisiana Maneuvers, and TRADOC's battle labs to test and experiment with new doctrinal concepts and technologies.[60] This approach relies heavily on simulation and modeling but also includes opportunities for soldiers to test "new methods and equipment in the field and on the ranges".[61]

The foregoing discussion has been necessary to appreciate the full scope of the intellectual and technological change which is currently taking place in the Army. There is a symbiotic relationship between the intellectual and technological changes. The intellectual ideas cannot be realized without the technology and the development of technology needs focus and direction in order to be useful. Michael Howard cautions "The fact that technological change is obvious as a problem does not necessarily mean that it is easy to foresee or to cope with. How do technical innovations affect the conduct of war? We have almost always got it wrong."[62]

In the Army's current situation, we cannot afford to be wrong. We are counting on these technological innovations to make up for a possible shortfall in force structure. The thrust of our modernization effort is to harness technology, especially computers and radios, to leverage information so that we can fight and win knowledge based warfare. It is incumbent on us to fully study how the technological innovations will affect the conduct of war so that our doctrine can be adjusted to achieve maximum benefit.[63] At the same time we must be cognizant of the fact that our modernization plans are nothing more than the logical extension of the traditional American way of war. Our traditional way of war has repeatedly resulted in strategic surprise at the beginning of war. Our task this time is to ensure that the peacetime changes in technology and doctrine are "about right" for the next war.

III. THE DYNAMICS OF KNOWLEDGE

> "...knowledge, as a resource, differs from all the others. It is inexhaustible. It can be used by both sides simultaneously. And it is nonlinear. That means that small inputs can cause disproportionate consequences. A small bit of the right information can provide an immense strategic or tactical advantage. The denial of a small bit of information can have catastrophic effects." [64] (Alvin and Heidi Toffler)

Functionally, we use the electromagnetic spectrum to see the battlefield, communicate, aim weapons, deceive the enemy, and to prevent the enemy from doing the same. Each one of these functions concerns the movement of information. For example, the *fact* that an enemy aircraft is approaching can be discovered by a radar. The radar operator can then communicate that information to a decision maker who then can use the spectrum to order an interceptor aircraft to launch. The interceptor aircraft then uses radar shadows to deceive the enemy aircraft as to the true location of his aircraft while he simultaneously jams him in case the deception fails. Finally, the pilot fires a missile that uses the infrared portion of the spectrum to feed terminal guidance information to the missile's flight control system.

The *fact* that an enemy aircraft was approaching was a piece of information which existed independent of our knowledge of that fact. It required the movement of that information first to the radar operator, then to the decision maker, to the pilot, and ultimately to the missile in order to realize all the potential energy of that piece of information. Simultaneously, we took actions to prevent the enemy from moving similar information. Almost all of the information that needs to move on the battlefield must use the electromagnetic spectrum to reach the intended receiver. Technology has enabled vast quantities of data to move around at an ever increasing rate. This has enabled armies to act increasingly faster and in a more coordinated manner. MOP 30, C2 Warfare, is aimed at making sure that our information system flows quickly and effectively while we take actions to slow and disrupt the enemy's. The end result being that our tempo will be greater than the enemy is able to achieve.

Any good armor officer can describe the characteristics of his munitions at their point of impact. He understands the relationship between terminal velocity of the projectile and the range of his target and its corresponding influence on effectiveness. Any good artillery officer can expound on the characteristics of his weapon's ballistic trajectory. He understands the relationship between range and the circular error probable of his weapon and its corresponding influence on effectiveness based on the bursting radius of his projectiles. Whether they realize it or not, they understand the operational principles of kinetic energy. Now, with the doctrine of information supremacy, we are coming to realize another form of energy that has an even greater potential for devastation, knowledge. Knowledge enables commanders to use their armed forces to create powerful military actions.

Kinetic energy is a function of mass and velocity.[65] The energy which comes from knowledge is a function of information and throughput. Like a bullet, a single piece of information can be thought of as having a certain amount of mass. Bullets can range from a very small amount of mass to very large. Information can also have a wide range of values in terms of its importance. Information theorists link the importance of information to the degree of uncertainty which the information resolves.[66] Also like the bullet, information performs no function until it is propelled from its point of origin to its target. It is not enough that the information simply move, it must be "aimed", i.e., delivered to the person or machine that can use it. Signal officers call this information path a needline.

Another similarity between a bullet and information is that, like the bullet, the more quickly information gets to its target, the greater its effect. The timeliness of information has a major impact on its value as knowledge. The sooner a piece of information arrives at its target, the more likely the information is still true and the more time leaders have to make decisions and take action. Likewise, the velocity of a bullet at its point of impact is a major determinant of the resulting energy which is transferred to the target. On the other hand, if the bullet misses, no energy is transferred. Similarly, if the information cannot be delivered to the intended recipient, its value quickly drops to zero.

The effect information has when it reaches its intended recipient is to increase knowledge. Knowledge of the battlefield is the energy which propels an army to battle. As Alvin and Hiedi Toffler noted, knowledge is nonlinear. Each piece of information which is added increases knowledge in proportion to the value of the information. Misinformation decreases knowledge with respect to ground truth but with respect to the perception of the leader it adds to knowledge. A professional and creative leader can use information such that its whole far exceeds the sum of its parts. On the other hand, misinformation or the lack of key information can have catastrophic effects.

By combining the effects of kinetic energy weapons with knowledge of the battlefield, we can achieve nonlinear effects. Returning to the single bullet for a simplistic example, the bullet can be used to shoot an enemy private and achieve a marginal effect on the battle. The same bullet can, if his location is known, can be used to shoot the enemy commander and thereby achieve a far more significant effect on the outcome of the battle. Of course, all this depends on the assumption that the enemy didn't determine our enemy commander's location and kill him first or that the enemy didn't somehow prevent those who knew the enemy commander's location from telling the person with the bullet. Therefore, we must take action to protect our information as well as our information flow. On a much grander scale, this is information operations and it is how the Army in the 21st Century intends to win decisively in spite of its smaller force structure.

The word 'energy' comes from the "Greek words meaning work within" and it applies to "any phenomenon capable of conversion into work."[67] Wind energy is converted into work by sails and water energy by water wheels. The energy in knowledge is converted into military action by battle command. Battle space is that space in which knowledge of the battlefield is germane to the commander's ability to create action. The greater the knowledge of the battlefield, the greater the work that can be done by battle command. Information operations seeks to expand the friendly commander's battle space while decreasing the enemy's.

In the physical realm, energy is called potential energy when mass is not in motion. Once the mass is in motion however, its energy is proportional to its mass and to the square of its velocity. Velocity is a vector quantity which captures both the direction of the mass with respect to a selected aim point and the rate of motion toward that point. This is quite different than the concept of speed which is the rate of motion independent of direction. A person driving 30 miles per hour due west but who wants to go to a town which is due east, has a negative velocity with respect to the energy expended to do the work needed to get to the desired destination. Similarly, if that person was driving in a northeasterly direction, he would be getting closer to the town, at least initially, but his rate of progress towards that town would be a fraction of his actual speed. The fraction would be the easterly component of his northeasterly direction. What the army wants to do with information operations is to move due east while sending the enemy in the opposite direction.

We've noted that information can be equated to mass in this model. Perhaps information "throughput" can be equated to velocity. Data is information to the extent that is has meaning which resolves uncertainty.[68] The same piece of data can have a wide range of relevancy or meaning to different people depending on their functions within the system and their pre-existing knowledge bases. This is the key to understanding the directional nature of information flow. Moving information to the right person in a timely manner determines the degree of knowledge created. Throughput should be thought of as an analogous term to velocity which embodies both the rate of information movement and its direction.

The aim of information flow is to move it from wherever it exists on the battlefield to the mind of the battle commander as quickly as possible. Like the physical realm, throughput, as an analogous term for velocity, is quite different than information rate or data rate. These terms are more analogous to speed. They measure the rate at which information moves through a channel without regard to whether the information ever reaches the mind of the person that needs the information. Information rate or data rate, from a communications electronics point of view, measures the flow of information in bits per second where the bits are physically moving at the speed of light. Throughput on the other hand involves the movement of the information to the mind of the commander though the combination of communications systems, computers, and manual processes such as battle staff procedures. This information may be combined and processed along the way in order to enhance its meaning or it may be lost along the way by an incomplete communication event, a faulty computer program, or an error in staff procedure. The cumulative rate at which all the relevant information on the battlefield reaches (or does not reach) the minds of the people that need it is what I call throughput.

Information and throughput and their relationship to knowledge and battle command can be used as a theoretical model to analyze military action throughout history. Martin Van Creveld has said that the quest for certainty has been a timeless characteristic of command.[69] What is changing in modern times is not the quest for certainty but rather the exponential increase in the throughput rate achieved by the combination of computers and the use of the electromagnetic spectrum to capture information and to transport it around the battlefield in digital form. By digitizing the battlefield, we hope to be able to leverage information to increase in efficiency to make up for what we are losing in size. This logic only works if we somehow prevent the other side from leveraging information in the same way while simultaneously overmatching us in size.

On one side of the equation, we degrade the enemy's ability to create effective military action by attacking his information, his throughput rate, and the minds of his leadership. We do this through operations security, deception, psychological operations, electronic warfare, and physical destruction.[70] On the other side of the equation we maximize our ability to create significant military action by simultaneously protecting our side from enemy counter actions while designing a system which moves greater masses of information with ever greater throughput rates. This competitive, destructive interaction is the same interaction which Clausewitz uses to describe the unique nature of war[71] and which J.F.C. Fuller poses as the ageless dilemma of combat, how to kill the enemy before he can kill you.[72] This is what makes information *warfare* an appropriate term.

The electromagnetic spectrum has a role on both sides of the information warfare equation. We use it to convey misinformation to the enemy and we use it to slow his throughput rate. On the other side of the equation we use it collect information and to accelerate throughput. However, it is quite important to note that the spectrum is only one part of the throughput problem. Returning to the example of the approaching enemy aircraft, we can see that using the radar portion of the spectrum, the data was simultaneously captured and transported back to the radar receiver. A computer then converted the data into an understandable form for the radar operator. The operator then compared the information to his knowledge base to determine if the information was significant and if any action was necessary. As time goes on, this function will be increasingly automated. If the information is deemed important enough, it will be passed on to the next appropriate station via the radio wave portion of the spectrum. There again, the information will be processed and added to the knowledge base.

The staff procedure or the automated process may or may not determine that the information needs to be presented to the decision maker for a decision. Even if the information does make it to the decision maker, he may not receive the full meaning of the information if the knowledge base has been affected by deception or psychological operations. Throughput in this case could be greatly accelerated by the use of digital systems which speed the processing of verified information through appropriately programmed computers and over robust, high capacity communications links to alert the commander of important information requiring a decision. On the other hand, throughput could be degraded or decelerated, by enemy deception, faulty information processing by computers or humans, or by incomplete communications events due to excessive range, interference or insufficient capacity.

In the physical realm, a mass must be moving to possess the energy needed to perform work. A mass which is not moving is being acted upon by equal and opposite forces which hold it in place. In order to impart motion to the mass, an unbalanced force must act on it for some period of time.[73] That force must be sufficient to overcome friction in order to accelerate the mass. Friction is also a force and operates in the opposite direction thus slowing the motion. It may be useful to think of electromagnetic waves as the force which moves information. Information is also subject to the opposite forces of friction. Forces whic. slow or block throughput on the digital battlefield can be called "digital friction" to differentiate it from the traditional sources of fog and friction.[74] While we have noted that the spectrum is not the only component of throughput, it is arguably the most significant.

IV. UNDERSTANDING THE ELECTROMAGNETIC SPECTRUM

Virtually all of the capabilities required by the modernization strategy and emerging doctrine makes some use of the electromagnetic spectrum. Computers need it to communicate. Sensors need it to see the enemy. Soldiers need it to talk and to see at night. Smart munitions need it to find their targets. The spectrum is the force which moves information on the battlefield enabling commanders to exercise effective battle command, to expand their battle space relative to the enemy's, and to conduct simultaneous operations throughout the depth of the battlefield. There is also a negative side to the electromagnetic spectrum. It contains forces which act against the movement of information and which serves to slow throughput. These forces are analogous to friction.

The electromagnetic spectrum is not a physical entity. It is a construct which is used to describe a physical phenomenon. Frequency can be thought of as the rate at which electromagnetic waves (crest to crest) pass a given point. It is measured in cycles per second (hertz). There are an infinite range of frequencies. The electromagnetic spectrum is the construct used to describe that range. The spectrum is broken down into sub-sections or ranges of frequencies in accordance with various sets of properties shared by each range. These properties gradually vary as you move from one end of the spectrum to the other in terms of their propagation characteristics and their resulting practical usefulness to man.

At the low end of the usable spectrum antennas would have to be extremely long (measured in miles) thereby greatly limiting their practicality.[75] On the other hand, low frequency signals can propagate through water or even the earth. Unfortunately, very little information can be encoded in the wave per unit time so the data rate at the low end of the spectrum is very low. At this end of the spectrum, antennas several miles long are used to talk to submarines.[76] Also, power lines and generators radiate low frequency emissions which can produce unique signatures.[77]

At the higher end of the usable spectrum, antennas become increasingly smaller and can be made highly directional.[78] Given a constant transmitting power, the greater the frequency the shorter the range of the signal. On the other hand, more information can be transmitted per unit time. Higher frequencies are strictly line of sight unless they are reflected off of some medium. Higher frequencies will not pass through water, the earth, or vegetation, but will reflect off ionized layers in the upper atmosphere or metal. Light is at the higher end of the spectrum and reflects off just about anything. That part of light which does not reflect is absorbed and quickly dissipates its energy in the form of heat. Radars, microwave and skywave radios, thermal sights, guided missiles, smart munitions, and laser range finders make use of the higher end of the spectrum just below and above the visible light portion of the spectrum.

These characteristics offer many possibilities for military exploitation while ultimately limiting the range of frequencies which have practical military value. For example, for tactical communications soldiers need an omni-directional capability because they are so mobile. They need to be able to communicate as far as possible with the least amount of power but they are limited by the size of the antenna they can use. Working at cross purposes to their desire for range is their desire for the highest possible data rate. Working against their desire for high data rates is the need for as many channels as possible to handle the great numbers of radio nets which will be operational in a relatively small area. The end result of these requirements and constraints is a compromise on the various competing demands which restrict tactical communications to the central part of the usable spectrum. Tactical communications are limited to the Very High Frequency (VHF) section of the radio band portion of the spectrum. For the same reasons, both allied and enemy tactical communications nets will also be found in this range as well as local television and radio stations.

Furthermore, within the useful range of frequencies, the number of channels available for use is restricted by the ability of modern electronics equipment to produce a precise frequency or to produce filters that operate at precise frequencies. For example, a single channel on the SINCGARS radio requires 25,000 frequencies (25 kilo-hertz). The modulated signal is transmitted on the frequency at the center of this 25 kilo-hertz band but has components throughout the channel. Even at that, it still can experience adjacent channel interference when the offending transmitter is relatively close. SINCGARS has 2320 of these 25 khz channels[79] but in any potential war, a little under 1000 of these channels would be restricted from use in order to account for allied and host nation frequency requirements as well as to prevent electronic fratricide by our own jammers and mobile subscriber equipment. That leaves approximately 1500 channels[80] to be shared by the 34,000 SINCGARS radios (organized into 3,400 radio nets) found in the standardized South-West Asia scenario Army Corps.[81] Key parts of the spectrum such as the VHF portion of the radio band are extremely crowded and the trend is toward increasing the number of users to accommodate both data and voice nets on the digitized battlefield. One of the key lessons learned by the US Army artillery after fifteen years of experience with digital data communications is that voice and data can not both function effectively on the same net.

Competition for use of the electromagnetic spectrum occurs at the receiver. The transmitter that is able to achieve the greatest signal strength at the receiver wins. Of course one technique is to destroy the offending transmitter. This is not always possible and in any case, the offender may be friendly. For a given frequency, the power at the receiver is a function of the power coming out of the transmitter and of the inverse square of the distance. In other words, every time the distance is doubled, the power decreases by a factor of four. Therefore, there is a great premium on being close to the intended receiver. Since enemy jammers must operate from the other side of the FLOT, they must operate at a relatively high power in order to be effective. Generally, the effect that jammers produce is to decrease the effective distance at which electromagnetic systems can operate. The farther apart a friendly transmitter and receiver are, the easier it is for an enemy jammer to achieve a higher power at the receiver. Radars are especially susceptible to interference since their received signal has to travel twice the distance to the reflected target.

Enemy jammers are not the only source of interference in the spectrum. Friendly emitters can also interfere. As mentioned previously certain segments of the spectrum are extremely crowded. In order for use of the spectrum to be effective, frequencies must be allocated such that users are assured sole friendly use of the spectrum at any given time. This is the function of Army spectrum managers. However, often times the user's requirements exceeds the number of available frequencies. In the past, one technique used was to allocate the same frequency to multiple users who would be operating far enough apart from each other not to interfere. Today, with the proliferation of radios, rapidly changing unit task organizations, and increasing battlefield mobility, this technique is no longer adequate. The VHF band is becoming saturated, effectively reducing the range capability of the transmitters, especially for data communications.

During Operation DESERT STORM, friendly interference was severe. In spite of the fact that there was near perfect electronic line of sight and no vegetation and the fact that the enemy did not jam our nets "Seventy-nine percent of the commanders said that they encountered significant communications problems".[82] A sampling of commander's comments follows: "..Never had as much trouble with commo as during DESERT STORM." "...units train with line units close enough to communicate with FM commo. Our inability to move and communicate effectively was a big surprise."[83] In addition to distances and tempo being greater during DESERT STORM than in peacetime training, the number of transmitters in a limited area far exceeded anything seen anywhere or anytime in history.

Over the past several years, many electronic techniques have been developed to help alleviate frequency band saturation and increase throughput. Electronic equipment has improved thereby allowing more information to be passed in a narrower bandwidth. SINCGARS has two channels in the same space its predecessor used for one. Other approaches include such techniques as time division multiple access (TDMA) and frequency hopping. In TDMA, multiple users use the same frequency by dividing a unit of time into multiple segments and then assigning each user his own segment.[84] In frequency hopping, the transmitter rapidly varies its frequency in a predetermined pattern. Every set of users in the band frequency hops according its own pattern across the same set of frequencies. In frequency hopping, electronic fratricide occurs, but each occurrence only lasts for the length of one hop. Unless the interference occurs on too many hops during the transmission for the information to be understandable at the receiver, frequency hopping provides a way to "share" frequencies.

Frequency hopping makes it very difficult for the enemy to home-in on the transmitter in order to locate it. Frequency hoppers can still be jammed but the jammer must put energy on multiple frequencies simultaneously thereby decreasing the amount of power on each frequency.[85] SINCGARS is capable of using the frequency hopping technique.[86] EPLRS uses TDMA and is also capable of using frequency hopping.[87]

Various types of information are affected by the dynamics of the electromagnetic spectrum differently. For example, data communications are far more fragile than voice. When small pieces of a voice message are lost, the human ear and mind can usually reconstruct the message without any loss of information. However, when pieces of a data message are lost, computers have only a limited capability for putting the message back together. When it fails, the entire message is lost rather than just the part that was corrupted.

As a result of this phenomenon, data communications have significantly shorter effective (80% message completion rate) communications ranges. For example, SINCGARS, using its highest power and most efficient antenna with perfect electronic line of sight, is only expected to be capable of reliably transmitting data messages 20 kilometers. The same radio transmitting voice is required to reliably communicate 35 kilometers.

Efforts to achieve better reliability for data transmissions cuts down on the data rate which can be achieved. For example, in order to achieve the 20 kilometer requirement, SINCGARS was designed with imbedded software which transmits each bit of a TACFIRE computer message 13 times. At the receiver, the best 7 of 13 bits is taken as the intended version of the bit. This process, combined with the embedded error correction protocols reduces the data rate from the radio's maximum capability of 9600 bits per second down to 1200 bits per second. Lower data rates mean more transmission time and therefore greater saturation of the frequency band. Greater saturation means more electronic fratricide, even for frequency hopping systems, and especially for data communications. Greater saturation also means its easier for the enemy to jam, especially data communications, because friendly emitters are doing at least part of the job for him.

Saturation is most likely to occur where there are a large number of radio nets in a small area and when there is a lot of communicating taking place. This tends to occur at places like the point of the main effort, breaching sites, and passages of lines while in contact. These are exactly the times that communication is most important and it is exactly the time our communications systems will have the most problems due to saturation.

During the SINCGARS Initial Operational Test and Evaluation (IOTE), efforts were made to simulate the combat electromagnetic environment of a brigade and then a division, and in later tests, a corps. Due to resource constraints the environment could only be simulated in small portions of the test area. Message completion rate data were collected over the entire test area while the test unit (1st Cavalry Division) conducted battalion on battalion maneuver exercises. Units were MILES equipped so that their interaction with the terrain and the enemy forces would be realistic. Results from the first test seem to confirm the theoretical predictions. Voice communications was largely unaffected by the presence of the simulated electromagnetic environments achieving a few percentage points better than the required 80 percent message completion rate (MCR). Data communications, on the other hand, dropped to 62 percent and had only a 48 percent MCR at ranges between 8 and 20 kilometers.[88]

The anti-spoof function of the radio had to be turned off in order to raise the MCR.[89] The anti-spoofing function limited SINCGARS' ability to conduct error correction at the receiver in order to prevent enemy forces to alter the message. In later tests, with the anti-spoofing function turned off, similar trends were observed with respect to data communications performance in the simulated electromagnetic environment although the MCRs were not quite so low as the first test. In both tests, performance was also degraded by jamming, especially when combined with the added noise of a simulated brigade, division, or corp's worth of frequency hopping radios.[90]

In normal training, greater MCRs and ranges can be achieved because the full complement of wartime transmitters are not present in the training area. In testing conducted by the Army Development and Employment Agency (ADEA) at Ft. Lewis, WA prior to the SINCGARS IOTE a realistic electromagnetic environment was not used and SINCGARS data MCRs were achieved in the high nineties.[91] This gave a false indication of the true performance potential of SINCGARS transmitting TACFIRE data in a wartime environment. As the Army works towards its goal of digitizing the battlefield, it would do well to learn from these past examples and spend the money necessary to create a realistic electromagnetic environment at its major training centers.

The end result of all this is lower message completion rates and therefore lower effective throughput. The lower the MCR or throughput, the more difficulty computers on the battlefield will have trying to achieve their stated purpose, i.e., common picture, situational awareness, and enhanced synchronization. Information flow is required to make the Army Battle Command System work. Slower information flow acts as a drag on the ability of units to conduct high tempo operations. The negative forces of the electromagnetic spectrum, combined with the actions taken against us by the enemy in the spectrum, create a sort of digital friction which limits throughput and therefore limits the ability to leverage information.

The question is often asked, why not go to higher frequencies for tactical radios since higher frequencies offer greater bandwidth and therefore greater throughput capability. The answer lies in the compromise with the physical laws of nature described earlier. Higher frequencies do not transmit very far and therefore must rely on specialized antennas to focus the power in a single direction. This means that communications shots must be lined-up in accordance with a prearranged receive site with known electronic line of site. These type systems work well for high capacity networks based on relatively fixed site nodes such as MSE. MSE's mobile subscriber receiver-transmitters (MSRTs) use the same part of the VHF band as SINCGARS in order to communicate through the nearest node to gain access to the MSE network. On the digitized battlefield, where we intend to dramatically increase our operational tempo, fixed site networks will have an even greater degree of difficulty keeping up, another form of digital friction.

Satellite relays for tactical communications have significant limitations. Aside from the fact that during operation DESERT STORM we operated at near capacity on our satellite links[92], the distance to the receiver advantage and the power generating advantage that enemy ground or airborne jammers would enjoy would be very difficult to overcome for units close to the FLOT. This is another concern for the digitized battlefield. Much of its initial value-added is expected to come from GPS satellite signals used to locate and provide navigation assistance to its soldiers in contact with the enemy. Initial operational testing of the GPS system showed that it is very susceptible to jamming.[93] This form of digital friction is induced by the enemy and has potential to negate much of the value added from digitizing the battlefield.

As engineers continue to search for more effective ways to use the spectrum, the tendency is towards increasing complexity for the users. This complexity is not without its operational effects. For example, to use SINCGARS in the frequency hopping mode, all the members of a given net must ensure that their radios are hopping on the right frequencies, in the right pattern, at exactly the right time in order to be able to talk in the net. These requirements have driven up the complexity of the radio itself as well as the procedures soldiers must use to operate them. During the SINCGARS initial operational test and evaluation (IOTE), the commanding general of the 1st Cavalry Division felt strongly enough about the added complexity of SINCGARS to write the following in a memorandum to the III Corps Commander:

> The most serious concern with SINCGARS equipment is the overall complexity of operations. At the operator, net manager, and leader levels, operations are exceedingly complex and demanding. Operators need much more extensive training than required with our current family of radios and these skills appear to be very perishable. Net management requires constant attention by senior NCOs and officers who have other warfighting duties to perform. Point of fact is that SINCGARS requires highly trained and disciplined operators, coupled with highly knowledgeable and alert net managers in order to obtain communications needed to perform command and control functions within a division. Attending to the requirements to operate the equipment and nets detracts from fighting/supporting the battle ... again an unacceptable condition.[94]

Other unintended effects of this complexity include the fact that eavesdropping on other nets is more difficult with SINCGARS. Eavesdropping is one of the significant lessons learned in Operations JUST CAUSE and DESERT STORM as noted in TRADOC Pamphlet 525-100-1, Leadership and Command on the Battlefield. Senior commanders cited eavesdropping as facilitating their "ability to obtain real-time information without having to get directly involved", "...an additional means of seeing the battlefield and another method for feeling the intensity of the fight", and "on at least three occasions...the prevention of fratricide."[95] The inability to eavesdrop is not limited to SINCGARS, it is a drawback to data communications in general as well. These effects while not directly attributable to the electromagnetic spectrum nonetheless decrease throughput and also act as another source of digital friction.

Other unintended effects include negative moral effects from the lack of voice to voice communications in the stressful environment of combat, the introduction of quantitization error from the attempt to quantify the otherwise infinite environment of combat for use by computers, and co-site interference such as that experienced by SINCGARS and MSE when on the same vehicle. It also includes the transmission of electronic signatures by Army electronic equipment. For example, TACFIRE computers are the only Army users of the 15 KW-400hz generators. Being at the low end of the frequency spectrum the signature signal would transmit for great distances if it had an efficient antenna. If the enemy could locate these 15KW generators, they could produce a complete order of battle for our artillery laydown and could easily target and destroy the brains of our artillery.

Each part of this system is vulnerable. Transmitter's can be intercepted, located and targeted. Receivers can be jammed or deceived, or destroyed. Electromagnetic waves can be reflected or altered. Like terrain, military use of the spectrum is subject to interaction with the enemy. The enemy can accept or decline battle to occupy key pieces of the spectrum. Adversaries can choose an offensive or a defensive strategy for confronting the enemy in the spectrum. Offensive actions include jamming and physical destruction (counter-C2). Defensive actions include actions to avoid enemy detection or jamming such as terrain masking, the use of directional antennas, or technical solutions such as frequency hopping or spread spectrum technology (C2-protect). Indirect approaches include use of the spectrum for the purpose of deception or PSYOPS, the interception of enemy communications, or the direction finding of enemy transmitters. The "paradoxical logic"[96] of war applies just as well in the electromagnetic spectrum as it does on the land, in the air, and on the sea.

Because the military use of the spectrum is interactive and reciprocal in nature with the enemy, a spiraling "technology" race will naturally ensue. Stealth technology was the reaction to radar proliferation. Frequency hopping was the reaction to jammer, interceptor, and direction finder proliferation. Chaff, flares, corner reflectors, and heated plates on armored vehicles are the reactions to smart munitions. It is only a matter of time before there is a reaction to stealth, frequency hopping, and the armored vehicle counter-measures or that computer viruses are introduced through the electromagnetic spectrum or that directed energy weapons are perfected. As the United States Military becomes more and more dependent on electronics for its qualitative edge it may become too tempting for an adversary to resist the explosion of a nuclear weapon high above his own territory safeguarding his own equipment underground while ours is destroyed by electromagnetic pulse.

As we move toward the 21st century and an era of smaller defense budgets this technology race should be cause for concern. While the per unit cost of these technological devices is relatively small, the required numbers make the total buy for each system exorbitant. For example, the SINCGARS radio was a multi-billion dollar buy for the Army and this does not include the life cycle training costs. With the added complexity of the radio and the fact that virtually every soldier who serves in the Army during the radio's life cycle must receive training, the life-cycle training cost also numbers in the billions.[97]

As the Army continues its post cold war modernization programs it must continuously strive to understand the effects on war that the changes will bring about. The Army's ongoing changes place a heavy reliance on the positive forces of the electromagnetic spectrum to move information around the battlefield. Perhaps the negative forces of the spectrum, especially with respect to digital data communications are little understood and under appreciated. Digital friction will create a drag on the throughput part of the knowledge equation. Digital friction results from the moral effects associated with data communications in place of voice, from the human factors engineering problems associated with technology infusion, from the quantitization error associated with trying to quantify the battlefield environment for use by computers, and from the communications problems associated with electronic fratricide (frequency hopping) and electronic warfare. On one hand we are digitizing the battlefield to reduce friction, enable better decisions, and to facilitate rapid actions to defeat the enemy. On the other hand, we are adding digital friction to the battlefield. Hopefully, the value added of digitizing the battlefield far outweighs the introduction of digital friction. Better understanding of this relationship will enable the Army to minimize digital friction while maximizing the positive forces of the spectrum to achieve the non-linear effects of knowledge. The relationship between our ability to harness the positive forces of the spectrum and minimize the forces of digital friction will, to a large extent, influence the value added of digitization and the degree of resulting combat power we can expect to trade for force structure.

V. ANALYSIS AND CONCLUSIONS

> If the enemy cannot gain accurate, precise, and timely information about an adversary, upon which to base his plans and with which to target his weapons, he will have been denied the ability to wage war. That is the definition of security, and is the Clausewitzian definition of victory.[98]

The United States enjoyed superiority in warmaking technology and the doctrine for its use during the Persian Gulf War. This combination enabled the U.S. led coalition in the Gulf War to achieve a strategic, operational, and tactical surprise over the Iraqi Army the scope and magnitude of which surprised even ourselves. Historically, such military successes have become the subject of great study by armies throughout the world. The technology and doctrine of Operation DESERT STORM is bound to be emulated to some degree both by allies and enemies alike. This realization has been an impetus for change in the United States Army. Another force for change has been the domestic realities of increasingly smaller defense budgets. The combination of these factors has fueled the post cold war modernization programs of the United States Army. The changes which the Army intends to undertake are profound. Already the size of the Army has decreased by almost fifty percent. Using the Gulf War as its "way point", the Army leadership's vision of the future involves the logical extension of the American way of war into the information age. The fundamental premise of the their concept for the future is that, through the use of integrative technology, the Army can achieve similar results with less forces by attaining greater efficiencies with the forces we do have.

Through the use of integrative technology, the Army envisions being able to more effectively project and sustain its forces, protect the force and preserve freedom of action, win the battlefield information war, conduct precision strikes, and dominate the maneuver battle. A doctrine of information operations is currently under development which would systematically ensure that friendly forces will enjoy a knowledge overmatch so that integrative technology can be used with decisive effect.

There is at least one significant shift in the direction of the new approach and the experiences of the Gulf War. Information operations extends the quest for knowledge overmatch down to the lowest tactical levels. During the Gulf War, the knowledge overmatch was greatest at the highest levels. The lower down the chain of command one went, the greater the frustration over the lack of useful information about the enemy and even about one's own forces.[99] Throughput at the tactical level was not adequate to meet the demands for information.

At the tactical level, United States forces were still using voice communications and map boards with acetate updated by grease pencils. Overmatch at the tactical level was in terms of weapons systems. However it was knowledge overmatch at the operational level which set the conditions for the tactical forces to be at the right place on the battlefield with overwhelming combat power at the point of impact. In the next war, the United States may not have the luxury and flexibility to put together a plan with overwhelming force at every point of impact. We may not be able to keep the entire 1st Cavalry Division in reserve. One of the outcomes of our emphasis on information warfare and integrative technology is that we will calculate required force ratios differently. We will expect to get more combat power out of smaller forces.

By extending integrative technology to the tactical level, the expectation is that similar efficiencies as were achieved at the operational level during the Gulf War can be achieved at increasingly lower levels of command. Ultimately, the platoon leader with the Inter-vehicular Information System (IVIS), who is expected to have a common picture of the battlefield and near perfect situational awareness is expected to be able to set the conditions for the individual tanks of his platoon to ensure that they will always be able to win their engagements with minimal casualties. While this has always been the platoon leader's objective, in the future he will be expected to use his knowledge overmatch to avoid the head-on collision and instead entrap or surprise the enemy in order to defeat him quickly and in detail.

Reports of all such engagements would be immediately sent via digital data communications to higher and adjacent units. Commanders would be able to discern opportunities as they occur. They would then be able to organize and launch actions to exploit opportunities even as they occur. Continuous situational awareness at all levels of command would allow such exploitations to be followed up by each level of command thus reaching operational depths rapidly and with minimal casualties. Domination of maneuver in this way would be made possible by the ability to conduct precision strike operations to disrupt counter-attack forces and to paralyze enemy command and control. None of this would be possible without the freedom of action which comes from knowing more about the enemy than he knows about you. This means winning the information war by protecting our own command and control while destroying or disrupting the enemy's command and control systems.

Knowledge is the energy which will enable commanders to create effective military action. Knowledge overmatch gives the commander a certain freedom of action regardless of whether his forces are in the offense or the defense and therefore will become a critical center of gravity of our forces in the 21st century.[100] Knowledge overmatch will be the primary source of power which will enable our forces will fight outnumbered and win.

Knowledge is the energy battle commanders use to create action. Battle commanders still will be required to use their artistic talents to determine the operational effects they want to achieve with smaller forces. Increased levels of knowledge as well as highly professional, quick thinking commanders will be necessary in order for our modernization plans to have the desired effect. The commanders should be judged based on their ability to make decisions and exercise leadership to constantly create actions aimed at seizing or retaining the initiative. Battle command systems should be judged based on the degree of accurate knowledge which can be presented to the commander in a timely manner.

Clausewitz recognized the futility of trying to provide the commander with perfect information in a timely manner. That is why he emphasized the role of genius in the commander.[101] It is also why he said that the best strategy is to be strong first in general and then at the decisive point.[102] Today, with the proliferation of information age technology, we are attempting to use information overmatch to ensure we can be strong at the decisive point since we will likely be outnumbered in general.

The need for "genius" is as great as ever because we cannot afford to be wrong. To misjudge the enemy's intent or to choose the wrong decisive points when outnumbered can have catastrophic consequences. With the decrease in the size of the Army and the increased reliance on information at all levels, we will see the need for exercise of the principles of operational art at increasingly lower levels of command.

Chances are that we will not have military geniuses at all levels of command and in every position. We must ensure that information throughput is maximized and that digital friction is minimized. These are both equally important tasks and represent two sides of the same coin. Our greatest vulnerability in both respects lies in our ability to control the electromagnetic spectrum. Staff procedures can be improved and computer programs can be fixed to ensure they do not hold-up the throughput of important information to the mind of the commander. The spectrum on the other hand is governed by the laws of physics and is directly subject to interaction with the enemy. Modernization plans thus far have emphasized the positive forces of the spectrum to move information. Very little attention has been given to the negative forces, namely digital friction. Digital friction may impose insurmountable barriers to the realization of the Army's modernization plans. We already know that data communications ranges are less than two-thirds the range of voice communications in a realistic combat electromagnetic environment. This runs counter to the prediction that we must continue the trend towards dispersion on the battlefield.

If knowledge can have non-linear effects, then digital friction can also have non-linear effects. How do we balance the potential for these negative non-linear effects against the need to be able to fight outnumbered and win? Our modernization plans envision, and in fact require, assured, global, seamless communications from the strategic to the tactical level. However, as we go from the strategic to the tactical level this criteria will be harder and harder to meet precisely because of the effect we hope to achieve, that is high tempo operations throughout the depth of the battlefield.

The case against digitization due to digital friction is not clear cut. So long as the positive aspects outweigh the negative effects of digital friction and the net effect is greater than our present system, there should be a value added. Perhaps we should be satisfied with value added to our present system. Knowing the value added that we can expect in a combat situation will help to convert the force ratios needed for combat in the 21st century. It will help to know if our force structure and doctrine is "about right". All the high technology precision guided weapons in the world may not be enough to win if we cannot get target quality data in time to hit the enemy before he moves and get equally accurate battle damage assessment data to decide if we need to hit him again. Measuring that value added will then become our most difficult task in guiding the modernization program into the 21st century.

If we consider Michael Howard's dictum that peacetime modernization proceeds by a three way dialogue between operational requirement, technological feasibility, and financial capability, then it may be best to consider the later two as bounds on the operational requirements. If we concede that tactical level data communications will be the technological long pole in the tent for digitization of the battlefield and that financially we cannot afford to replace our current systems in the near future, then perhaps it is best to proceed along a near term modernization course within these constraints. Hard choices must be made to limit the rate at which we digitize to ensure we do not exceed our throughput capacity.

Currently, the Army does not have a solution on the combat information throughput capabilities of its systems. We know the data rate each system can achieve and we have product improvement programs in progress to increase those data rates but we simply do not know what to expect in terms of the aggregate rate at which our commander's information needs can be met. Information throughput is measured from the point of origin to the mind of the commander. Information requirements at every node as well as communications needlines are still being identified.[103]

The impact of frequency saturation on the 21st century battlefield is also an unknown other than to say that it will reduce effective communications range, especially data communications. Data from previous testing was based on a partial environment using TACFIRE as the data source in units that were using 20th century doctrine. These issues are so technically complex that they defy simulation. Data must be collected on actual units conducting force on force exercises within a realistic electromagnetic environment. The cost of doing this is expensive but given the fact that learning the impact of digital friction on the battlefield will be too late, we can hardly afford not to do realistic electromagnetic environment testing and training now. The data which would result from this type of testing in terms of realistic throughput rates can then be used in simulations to predict the value-added of new systems and doctrine.

On the macro level, value added as a result of the Army's modernization programs should be in terms of the net progress towards the program's objectives. Those objectives go beyond the five capabilities envisioned for the battlefield of the 21st century. The value added should be measured in terms of the synergistic effect that the combination of the five capabilities adds to our current ability to conduct relentless high tempo operations to seize and retain the initiative in pursuit of a quick decisive victory with minimal casualties on the 21st century battlefield. Failure to understand where we are with respect to this value-added analysis can lead to miscalculations which result in strategic surprise on the future battlefield.

This value added analysis needs to be broken into two parts. First is battle command. All the 21st century weapons and information systems will not be effective without effective battle command to use knowledge overmatch to create effective simultaneous actions throughout the depth of the battlefield. The second is an effective command and control system which ensures that the battle commander has the requisite knowledge with which to go about the work of creating military actions.

Initiative is an appropriate measure of battle command effectiveness.[104] Commanders create military action using the forces which they have been allocated in order to achieve effects which will lead to the accomplishment of their mission. Tempo is defined as the "measure of time between and the sustained frequency of militarily significant events."[105] Since commanders use their forces to create these events, it is incumbent upon the commander under our emerging doctrine to continually strive to increase the tempo in order to force the enemy into a reactive mode. The end result of this competition in terms of tempo is to seize and retain the initiative. The side that is able to set the tempo of operations possesses the initiative. Competition for the initiative in terms of tempo can be won in both the defense and the offense if the commander enjoys a decisive knowledge overmatch with respect to his enemy and is able to exercise the art of military decision making and leadership to utilize that knowledge with decisive effects.

Throughput should be the measure of value added for the command and control system. In the past the measure of a command and control system has been the "ability to function more effectively and more efficiently than the enemy's."[106] This measure is based on the Observe, Orient, Decide, Act (OODA) loop model of decision making. This model may not be appropriate for the 21st century battlefield. The objective for the 21st century battlefield information system is to provide the commander with near real-time complete situational awareness, a common picture of the battlefield, and total asset visibility. In this environment of continuously updated near real-time knowledge of the battlefield, the concept of a decision loop may not be useful as a measure of value added. On the 21st century battlefield we want commanders to already know what they need to know when they discern a need to make a decision. The standard for the future is continuously maintained clarity as to the battlefield situation so that decisions can be made rapidly when needed. Measuring value added against this standard is a function of information throughput.

Throughput in its broadest sense begins with the assumption that the needed information exists on the battlefield somewhere and must be made known to the person who needs it. Throughput in this sense includes the processing of information into graphical displays so that a "thousand words" can be said with a single picture. It also includes the interpretation of information by intermediaries such as computers, staff officers, or suoordinate commanders. Finally, and perhaps most significantly, it includes the movement of information through the electromagnetic spectrum. Throughput in this medium is a function of both data rate and message / call completion rate. Frequency saturation, range limitations, line of sight restrictions, complexity, and enemy interference all contribute to the failure to complete messages or calls. The degree to which commander's information needs are met on a near real-time basis is the only true measure of the 21st century battlefield information system. What they do with the resulting knowledge is a function of battle command.

Even without enemy interference, digital friction alone will be capable of preventing the full realization of the command and control system's objective. The only way to ensure that U.S. forces enjoy an absolute knowledge overmatch is to disrupt or destroy the enemy's throughput while protecting our own. This is the aim of information operations and, on the 21st century battlefield, it will be what higher commanders will do to set the conditions for their subordinate commander's success. Disruption or destruction of the enemy commander's ability to gain real time knowledge of the battlefield will be the crucial dislocation effect desired by commanders at every level as a prelude to commitment of their ground forces.

U.S. Army doctrine defines the military center of gravity as the "hub of all power and movement upon which everything depends. It is that characteristic, capability, or location from which enemy and friendly forces derive their freedom of action, physical strength, or will to fight."[107] The Army's information operations concept and this analysis indicates that the Army's modernization program will make knowledge a key center of gravity in 21st century warfare. The Army intends to use knowledge overmatch to maximize the potential of a smaller force armed with more lethal weapons in order to win quick decisive victories with minimal casualties. Knowledge overmatch gives the creative battle commander freedom of action in his plans, nonlinear strength in his forces, and the confidence which is so important to the will to fight.

In its efforts to ensure that it enjoys information overmatch, the Army is becoming extremely dependent on the electromagnetic spectrum. The spectrum possesses characteristics which facilitate the movement of information but it also has serious limitations which are governed by the laws of physics. Extreme reliance on the spectrum will cause it to be our Achilles Heel in the 21st century. Not only are there physical laws which will ultimately limit the utility of the spectrum, but also the spectrum is the enemy's primary medium through which it can identify and disrupt or destroy our information system.

There are two lines of operation which lead to our ability to achieve knowledge overmatch. The first is information itself. The side that can best conceal or distort information through operations security or deception respectively will enjoy a marked advantage. The second is throughput. The side which can disrupt or slow throughput will enjoy a marked advantage in the competition for knowledge. Domination of the electromagnetic spectrum constitutes decisive points on both lines of operation. FM 100-5, Operations, states that decisive points are "keys to getting at centers of gravity....Decisive points help commanders gain or maintain the initiative. Controlling these points in the attack helps them gain freedom of operational maneuver...If the defender controls such a point, it interferes with the attacker's momentum...".[108] Spectrum domination is achieved by competition for signal strength at the receiver or by physical destruction of his transmitters and receivers. Both lines of operation may be used but the operational effect which is desired is the dislocation of the enemy so that friendly forces can strike simultaneously throughout the depth of the battlefield before the enemy can react.

Viewed in this way, these decisive points can be considered pivots of maneuver for they help to gain freedom of maneuver, they maintain the momentum of the attack or counter-attack, and they help retain the initiative. On the other hand, each of these decisive points can be considered critical vulnerabilities which will lead to our own cente. of gravity. This implies the need to protect these decisive points.

The role of the electromagnetic spectrum on the future battlefield cannot be viewed in isolation. The spectrum will be a decisive point and a pivot of maneuver. It will be the force which propels information around the battlefield and it will be a source of digital friction which will prevent our goals for digitization from ever being realized. It is only one component of throughput which when combined with information creates knowledge in the mind of commanders. The spectrum is not analogous to a piece of terrain which can be occupied and held, rather it is a means to an end, knowledge overmatch. First and foremost, the electromagnetic spectrum is a construct used to describe a physical phenomenon. As such it is subject to the laws of physics and will ultimately define the limits of what we can achieve on the 21st century battlefield in information operations.

Finally, we must keep in mind that knowledge is only the energy which enables the battle commander to create action. Education of commanders in the dynamics of knowledge and the role of the electromagnetic spectrum will be crucial for effective battle command on the 21st century battlefield. Stephen Rosen, author of Winning the Next War, states that past peacetime changes have generally taken a generation to produce a functioning combat capability.[109] To the extent that the pace of modernization exceeds the capacity for leaders to assimilate technological and doctrinal changes, we may create a window of vulnerability in which we will be subject to strategic surprise by a well prepared enemy. Testing and training in realistic electromagnetic environments is a crucial first step towards ensuring the pace of modernization and the rate of assimilation by commanders stays in balance.

ENDNOTES

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4 Gordon R. Sullivan, "Moving into the 21st Century: America's Army and Modernization", Military Review, (July 1993) p. 2.

5 Michael Howard, "Military Science in an Age of Peace". Chesney Memorial Gold Medal Lecture given on 3rd October 1973. Michael Howard is often quoted as having stated that the best military leaders can do in peacetime is get their preparations "about right" prior to the next war.

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7 Data communications are more fragile than voice because it takes less interference to cause a data message to be aborted by the receiving computer. In a voice message, the human ear and brain can fill in the gaps when there is intermittent interference. In data communications, error correction protocols have only limited utility and if a message is corrupted, the entire message is lost.

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[17] Michael Howard, "Military Science in an Age of Peace", p. 2.

[18] General Gordon R. Sullivan and Colonel James M. Dubik, "Land Warfare in the 21st Century", Military Review, (September 1993), paragraph summarized from page 13.

[19] Sullivan and Dubik, "Land Warfare in the 21st Century", paragraph summarized from pages 14-18.

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[21] Sullivan and Dubik, "Land Warfare in the 21st Century", p. 25.

[22] Sullivan and Dubik, "Land Warfare in the 21st Century", p. 24-26.

[23] Sullivan and Dubik, "Land Warfare in the 21st Century", p. 27-28.

[24] Sullivan and Dubik, "Land Warfare in the 21st Century", p. 29.

[25] Sullivan and Dubik, "Land Warfare in the 21st Century", p. 29-30.

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[28] Sullivan and Dubik, "Land Warfare in the 21st Century", p. 31. General Sullivan quotes Martin van Creveld, Fighting Power(Westport, CT: Greenwood Press, 1982), p. 3.

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[32] Sullivan, "Moving into the 21st Century: America's Army and Modernization". p. 7.

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